Fabrication of Micromirror Array with Vertical Spring Structure

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Abstract - A 50 × 50 μm^2 aluminum micromirror array is fabricated using surface micromachining technology. 50 × 50 micromirrors are arrayed two dimensionally. The micromirror plate is supported by a vertical spring structure that is placed underneath the mirror plate. When the mirror plates reflect a light, the micromirror array can have large effective reflecting area. Fabrication of vertical spring uses only one mask and shadow evaporation process.

I. INTRODUCTON

Micromirrors are of great interest for dense light modulator arrays for use in laser printing and projection display system. There have been aluminum torsional mirrors[1~2], silicon torsional mirrors[3], and poly-silicon torsional mirrors[4] reported. And the aluminum torsional mirror has been improved further to the hidden-hinge model by Dr. Hornbeck[5]. The hidden-hinge model has torsional hinges with yoke underneath a mirror plate, so it has larger effective reflecting area than the previous model. The improvement costs more complicated fabrication steps and increased number of masks.

This paper reports a fabrication method of micromirror array with different mechanical spring structure, and with reduced fabrication steps. It adopts a vertical spring that is not revealed to a surface of a device because it is placed underneath a mirror plate(Fig. 1). The vertical spring is fabricated by shadow evaporation, and this process requires no additional mask to define the spring. The mirror plate is a square and 50 μm on a side and the mirror array is designed to have about 88% active area.

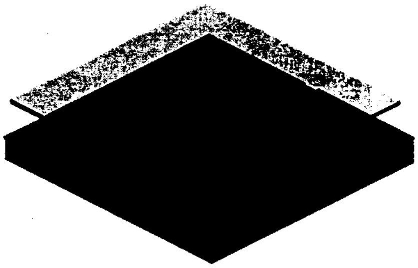

Fig. 1 Schematic view of micromirror

II. FABRICATION

Figure 2 describes a fabrication process. The first(Fig. 2-a) is electrode deposition and definition step. And an aluminum electrode layer is evaporated on thermal oxide layer and patterned. The thickness of both layers is 1000 Å. Second (Fig. 2-b), a thick photoresist sacrificial layer is spin-coated to a thickness of 5 μm. The sacrificial layer is patterned into a hole with a trapezoidal cross section using oxygen RIE(reactive ion etching). The process conditions of hole patterning are summarized in TABLE I. A short side of the trapezoid is 3 μm, a long side is 6 μm, and a distance between two sides is 3 μm. We decide a hole with trapezoidal cross section because we want to use three sidewalls of the hole as the shadow mask for evaporation of spring metal. When we evaporate the spring metal with some incident angle, the spring metal is deposited only on the long sidewall of the hole. It is because only the long sidewall of the trapezoid can be seen from the evaporation source point. With the shadow evaporation process, we can define a vertical

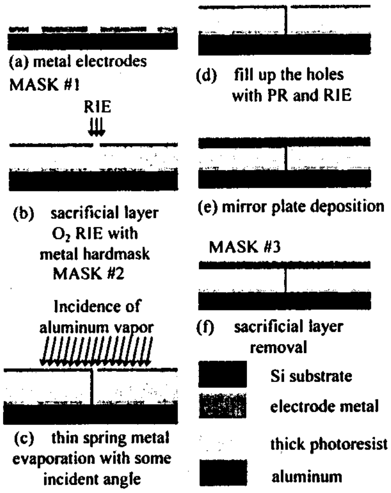

Fig. 2 Fabrication sequence of micromirror with vertical spring structure

TABLE I Summary of anisotropic RIE conditions used in hole patterning

RF power	200 W
Chamber pressure	50 mTorr
Gas flow	50 sccm
Etch rate	0.4 μm/min

spring without additional photo-lithography. Only one mask is required to define a thin mechanical spring structure. The third step(Fig. 2-c) is evaporation of spring metal with some incident angle. In my experiment, the incident angle was 20~40 degrees and the thickness of the spring metal was 1500~3000 Å. The next step(Fig. 2-d) is filling up the hole with thick photoresist. And an oxygen RIE step is performed to make the two thick photoresist layers(step b and step d layers) have the same thickness. The next step(Fig. 2-e) is mirror metal(aluminum, 0.8 μm) evaporation and patterning. Because we filled the holes up, the aluminum vapors are not deposited on the spring. The mirror plate can be fabricated thicker than the spring in this way. And finally we remove the thick photoresist sacrificial layer using isotropic oxygen RIE process(Fig. 2-f)[3].

III. FABRICATED MIRROR STRUCTURE

Fig. 3(a) shows a top view of the micromirror array. The micromirror array has 2,500 pixels. The incident angle of shadow evaporation was 30° and the spring thickness was 2500 Å for this sample. Some mirrors were deflected about 6° after sacrificial layer removal. We think the initial deflection was caused by non-uniformity of the evaporation process(difference of incident angle according to position in the sample). Because the evaporation source is not a point source but has some area(5 × 45 ㎟, rectangular boat), the incident angle of shadow evaporation is not constant but has some deviation(± 6.5°) according to position in the sample. Fig. 3(b) shows a side-view of micromirror array. Mirror plate is about 1 μm thick and it is suspended by a vertical spring structure.

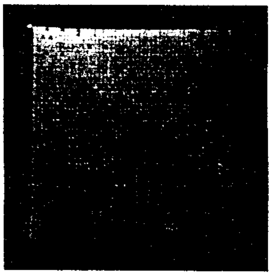

Fig. 3(a) Top view of 50 × 50 micromirror array

Fig. 3(b) Side-view of some pixels

Fig. 3 SEM photograph of fabricated mirror

Fig. 4(a, b) shows a spring structure where mirror plate is lost. In the places where mirror plates are lost, there were no spring structures. Only a few springs without mirror plate can be found and we can conclude that the failure was caused by poor adhesion between a spring and a substrate. Fig. 4(a) shows a successfully fabricated spring structure which looks flat. On the other hand, Fig. 4(b) shows a spring which is not flat. The pixel with a spring of Fig. 4(a) was initially deflected about 6° and landed on the substrate by applying about 20 volts of voltage difference between a mirror plate and an address electrode. But, the pixel with a spring of Fig. 4(b) deflected only slightly by applying 40 volts of voltage difference. Some of them began to move by applying large voltage difference as large as 60 volts. And once they've begun to move, they deflected fully by applying smaller voltage difference of about 35 volts. But they did not return to their initial position after deflection, but deflected about 3° from their initial position. Some pixels with springs of Fig. 4(b) deflected only slightly even by applying large voltage difference of about 80 volts. The reason is that the spring is not flat as we have designed, and the stiffness of the spring is very large. In one sample, there were some pixels with flat springs and some with not-flat springs. This also results from a non-

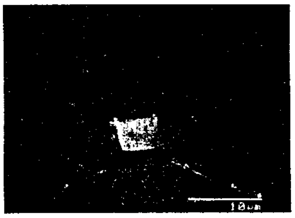

Fig. 4(a) SEM of spring structure successfully fabricated

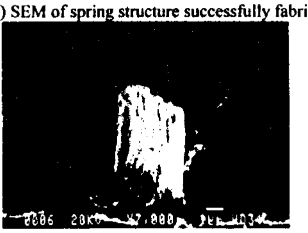

Fig. 4(b) SEM of spring structure which is not flat

Fig. (4) SEM photograph of spring structure uniformity of shadow evaporation process. From these results, it is concluded that the uniformity of shadow evaporation process is very important in fabrication of micromirror array, and so the uniformity of evaporation process must be improved.

IV. CHARACTERISTICS OF MIRROR

Static and dynamic characteristics of fabricated micromirror pixel are measured using a laser based optical measurement system[2]. We measured a static angular deflection of a micromirror. We increased a voltage difference from 0 to 50 volts and the deflection of the micromirror was measured by PIN photodiode at the same time. Fig. 5(a) shows a wave form of applied voltage and output voltage from PIN photodiode. As an applied voltage increased, the deflection angle increased. When the voltage increased to about 34 volts, the mirror plate suddenly landed on the substrate. And the mirror plate suddenly released from the substrate when the voltage was reduced to 14 volts. Fig. 5(b) is a plot of deflection angle vs. applied voltage. The mirror was designed to have 10° of maximum deflection, but the maximum deflection was only 6.4° in this mirror. It is because the micromirror did not return to its initial position but it deflected about 3° from its initial position as already mentioned in section III. As a result, the maximum deflection was reduced to 6.4°.

Dynamic characteristics of the micromirror were also measured with the same measuring system. A step voltage was applied and the motion of the micromirror was measured by PIN photodiode. Fig. 6(a) shows the motion of micromirror when 50 volts of step voltage was applied. In this case, a rise time of the micromirror was measured to be about 150 μs. And in Fig. 6(b), dynamic response of micromirror can be seen when step voltage was 80 volts. In this case, a rise time was measured to be about 140 μs.

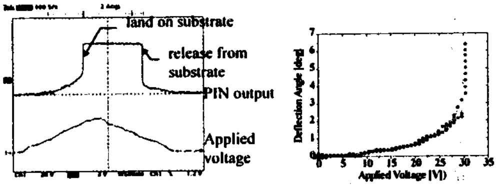

Fig. 5(a) Wave form of applied voltage and output from PIN detector

Fig. 5(b) Plot of deflection angle vs. applied voltage

Fig. 5 Static characteristics of micromirror

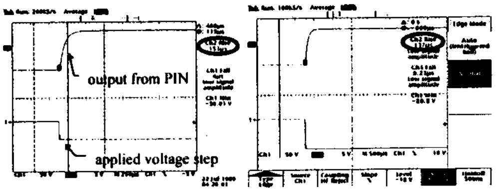

Fig. 6(a) Dynamic response of micromirror (50 V step applied)

Fig. 6(b) Dynamic response of micromirror (80 V step applied)

Fig. 6 Dynamic response of micromirror

V. CONCLUSION AND FUTURE WORKS

A micromirror array with vertical spring structure is fabricated with surface micromachining. Because the mechanical spring is hidden underneath the mirror plate, the array can have large active area. With shadow evaporation process, the micromirror can be fabricated with reduced fabrication steps, and with reduced number of masks. Comparing with the hidden hinge model of Dr. Hornbeck, the shadow evaporation requires only one mask while the hidden hinge model requires several masks. Static and dynamic characteristics of micromirror with vertical spring have been experimented. The mirrors touched the substrate by applying 20~35Volts. And the rise time was about 140 μs when 80 volts of step voltage was applied. But the vertical springs were not all fabricated as designed. The non-uniformity of shadow evaporated vertical spring results in non-uniformity between pixels. Future works will be devoted to improvement of uniformity in the shadow evaporation process. And mechanical properties of vertical springs as life-time, fatigue and stiffness must be modeled or experimented in the future.

VI. REFERENCES

[1] L. J. Hornbeck, "Deformable-Mirror Spatial Light Modulators", Spatial Light Modulators and Applications III, *SPIE Critical Reviews*, Vol. 1150, pp. 86-102, August 1989.

[2] J. W. Shin, et al., "Fabrication of Micro Mirror Supported by Electroplated Nickel Posts", *Proc. SPIE*, Vol. 2641, pp. 88-95, 1995

[3] H. Toshiyoshi, et al., "Fabrication and Operation of Electrostatic Micro Torsion Mirrors for Optical Switches", *Technical Digest of the 14th Sensor Symposium*, pp. 275-278, 1996

[4] V. P. Jaecklin, et al., "Optical Microshutters and Torsional Micromirror for Light Modulator Arrays", *Proc. IEEE Micro Electro Mech. Systems Workshop*, pp. 124-127, 1993

[5] L. J. Hornbeck, "Current Status of Digital Micromirror Device(DMD) for Projection Television Applications", *Proc. IEEE IEDM*, pp. 381-384